

# Improvisation in High-Reliability Organizing (HRO): 1. Red Noise Engagement

Daved van Stralen, MD, FAAP, Sean D. McKay, Element Rescue, LLC, Thomas A. Mercer, RAdm, USN (Retired)

## Abstract:

*Red noise produces functions forcing a response from a population. Pink noise creates abrupt catastrophic change that may require resetting or changing learned behaviors at the moment, if not starting over. For some reason, the organized approaches for these situations derive from stable white noise environments. These environments differ significantly in stability versus change, thought, information, precision versus accuracy, error versus correction, decision-making, and problem-solving. Red noise environments limit our ability to design for forcing or abrupt events effectively. These events cannot be deflected, contained, or suppressed. Entering the environment by way of improvisation is a practical approach to engagement. Operational organizations have decades of history of engaging in dangerous contexts.*

## Introduction:

Descriptions of HRO often come from spectators far from the hazards of High-Reliability Operations. When the pragmatics of operations are translated into more abstract normative statements, nuances, fine-tuning, and subtle but essential cues tend to be lost. This results in the incomplete translation of HRO theory into practice.

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Think of a group of experts watching a sports competition between two teams. While the teams compete on the playing field, the experts observe from the stadium's upper level. The experts are unfamiliar with the game, its rules, and its scoring. However, they immerse themselves in debate, identifying the likely rules and

figuring out the tactics and strategies used by each team.

One of the authors (DvS) would present this story to HRO educators and consultants who asked him why he continued investigating the mechanisms of HRO. They believed academicians had defined HRO, and we should now develop measurement tools and study its implementation. The author drew upon the difference between knowledge by acquaintance (the players) and knowledge by description (the experts in the upper seating tiers of the stadium). HRO occurs at a granular, local level in a rapidly fluctuating, unsafe environment. For their safety, spectators need to be protected from harm.

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Another reason for that author's view was his experience with retrograde intubation (1). This technique introduces a needle through the cricothyroid membrane in a cephalad direction. A wire is inserted upward through the nose allowing an endotracheal tube to be passed into the trachea. The key to the success of this technique is that the guide wire is held taut as the endotracheal tube is gently slid down the guide and into the trachea. This minimizes the risks of the endotracheal tube “flipping” out of the larynx.

However, he found that some emergency physicians were unsuccessful with this technique because they did not hold the guide wire taut as they inserted the endotracheal tube. The author identified a pattern by comparing the early literature and later review articles. Earlier published reports of retrograde intubation stressed the need to maintain tension on the wire guide. Later review articles did not mention that. This case illustrates the value of understanding the importance of subtle aspects of the technique (2).

Various operational gaps exist between theory and practice (3), but the most severe gap is between stability and entropy. Stability occurs in relatively closed systems that limit energy flow into the environment. The environment has the necessary buffering capacity to absorb or neutralize energy added to the system, much like white noise counters ambient noise to give a sense of quiet. This is much like the hospital environment where the environment does not intrude, emergencies are local and limited in scope, and responders have prescribed capabilities. These are “white noise” environments (4).

On the other hand, environments may experience energy fluxes with long periods such that events are few and far between. These

wavelengths carry the power to force a response; they are called forcing functions. The longer periods, like the longer frequencies of red light, are called “red noise” (4). A unique pattern occurs at the  $1/f$  frequency when an abrupt but rare event occurs. This is called “pink noise” because it has a frequency midway between white and red noise (5).

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The gap between white and red or pink noise becomes serious when principles and practices developed in white noise environments become expectations for red and pink noise environments. The abrupt change caused by pink noise can impair cognition and engagement (6), while forcing functions in the red noise environment are more likely to respond to effective on-scene improvisation.

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It is the red noise environment where rules conflict or compete, or the gaps between rules can lead to severe consequences. Initiative and improvised action bring resolution to these situations. However, this appears to be unconstrained “freelance” behavior to a spectator from a white noise environment. This is particularly

true within the culture of healthcare. They miss the importance of the initiative to immediately engage uncertainty and threats, and creativity to improvise solutions to novel problems.

Using white noise thinking and methodology as a lens to understand the unexpected, forcing functions, and abrupt change is fraught with risks and hazards. Classifications and standards developed in white noise environments impair operations during red noise forcing functions or when encountering abrupt pink noise events. Unnoticed causations, missing information, corrupted communication, and other influences are washed out when spectators evaluate the situation from a safe distance (7). Red noise operational interpretations become washed out for management, planning, and conceptual tractability (8). Mistranslating field terms into the business and management science lexicon removes essential concepts and themes developed through experience (9). “Leadership” as an *ex officio* label for executives, administrators, managers, and supervisors washes out the leadership characteristics necessary for liminal events and dangerous contexts (3). Decontextualized white noise operational formats eventually wash out the function of HRO (10).

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We can readily bridge the gap between white and red noise environments. That is not the problem. What has occurred in high-risk operations is the privilege gained by those with expertise in stable, white-noise environments. Lost in the development of HRO studies is improvisation as the engine of High-Reliability Organizing.

#### **White Noise Environments:**

Oscillating and fluctuating processes create frequencies of power. In some environments, the spectrum has an equal distribution of all frequencies with constraints on the power variance in all the frequencies. This is a ‘white noise environment’ with a frequency value  $f^0$ , named after the white noise in acoustical systems.

‘White noise’ is environmental noise with a flat spectrum uniformly spread across all frequencies ( $1/f^0$ , a constant). There is an equal and independent representation of energy over all frequencies *without* autocorrelation (feedback) and (11, 12).

- The equal distribution of energy means no dominance by any frequency—events become independent.
- Uncorrelated in time and independent of past events means there is no autocorrelation (feedback) of frequencies—events become random.

White noise frequencies,  $1/f^0$  (a constant), generate a normal distribution with zero mean and constant variance and is uncorrelated in time (in a time sequence, the value at time  $t$  is random and independent of the value at time  $s$ ). ‘Gaussian’ white

noise has a normal distribution of mean 0 and standard deviation 1. This makes statistical analysis and probability calculation possible and the development of reliable models and theories. Environmental elements are fully independent. Variance decreases over time or with increasing data. White noise environments are sensitive to information—more information increases precision.

The predictability of white noise environments informs the normative stance (13) and is the ideal scientific environment. For example, there is no energy exchange with the external environment, while the independence and randomness of elements support statistical analysis and probability predictions.

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Therefore, the presumption of a white noise environment has excellent utility for routine operations, research, scientific advances, support for academic medical care, and communication. Critical for clear thinking and problem-solving, the presumption of white noise gives tractability to an actual world that too quickly appears ambiguous, inconsistent, and disordered.

#### *White Noise Stability*

Because all frequencies are represented in white noise, it can cancel minor perturbations like white noise in the sound spectrum. The capacity to buffer interferences creates intrinsic stability. This does not mean that surprises will not occur. Novel properties can emerge from the stochastic resonance that creates environmental noise (14). It is the appearance of stability that masks systemic weaknesses.

A slow change in white noise environments produces a sense of stability—that the system is not changing. White noise environments favor the generalization of a population over periods that extend longer than the life of individuals (15). A person entering a white noise workplace develops a baseline for expectations. The system change is noticed only from entry and remains within the individual's experience. During slow change, one may long for the earlier, 'better' times. This “reset baseline” conceals or obscures change (16).

The stability of a white noise environment permits context-free concepts, theories, and problem-solving. Leadership becomes less critical than executive, administrative, and managerial skills (17), where 'categorical work' creates classifications and rules to work by (18). Classifications (18) and abstractions (19) gain greater significance. Experts develop mastery over distinct bodies of knowledge. Rather than experiential empiricism, theories, beliefs, and experimental empiricism become privileged. The individual accepts the new generalized norms and normative values. There begins a loss of practical wisdom as new abstract beliefs become privileged. Beliefs change, and the culture follows.

Deviation from accepted values is the error measurement for the

organization's response. The variance of white noise is almost constant, which allows for more accurate planning.

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Fluctuations in forcing function with exceedingly long periods or infrequent abrupt changes give the appearance of a stable environment if not a stable world. A red noise environment is readily mistranslated as a relatively stable white noise environment. Systemic weaknesses and leadership pathologies become masked.

The novice, though, will be challenged by the constrained stochastic surprises of the white noise environment.

#### *White Noise Thought*

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Concepts provide the necessary elements for comparison, standardization, and quantification. This use of concepts has become a foundation of modern science (20). The Linnaean system categorizes typologies into taxonomic hierarchies to show relationships. ICD-10 codes create discrete categories out of continuous public health data analysis processes. The categories of evidence-based medicine are intended to reduce waste and medical complications.

In the predictable white noise environment, the return to the previous state, homeostasis, becomes the goal of stability. Resilience describes system recovery to the previous norms. Less experienced personnel have reduced demands. Therefore, they need less supervision (11). Adherence to protocols and algorithms soon usurps initiative, creativity, and independent thought.

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#### *White Noise Information*

In the white noise environment, information is similar to Immanuel Kant’s idea of concepts—all concepts exist. Because there are no disruptions, information exists, is stable, and is accessible. The Gaussian distribution is information-dependent. Therefore, collecting more information decreases variance. This makes it easier to treat problems as a puzzle (21). After we collect the puzzle pieces, we have the answer—a form of deductive reasoning.

Information is also discrete, excluding middle values. The information does not contradict other information in the same context. The information does not change. Classical logic serves well in the context of a white-noise environment.

However, this has a great influence on arguments. If information cannot contradict other information, and there is no gradation of information, then we can disprove someone’s idea by focusing on contradictions and inconsistencies. To disprove one point disproves all. We encounter these individuals as the ones focused on normative values and distracting minutiae.

#### *White Noise Precision and Error*

Data in white noise environments form a Gaussian distribution. Collecting more data narrows variance, making white noise systems *information dependent*. Therefore, it is reasonable for those in business management to be “data-driven.” Increased data can also reveal the presence of distinct populations, such as in a bimodal distribution or a distribution with ‘fat tails.’

Precision is a measure of reduced variance in a Gaussian distribution. The Gaussian distribution can produce normative values capable of error measurement. Defining error as the distance from the desired or expected (normative) value allows

us to use error as a measure of precision. Because white noise systems are information-dependent, collecting more data reduces variance and gives more meaning to error measurements. In systems that require or value reductions in variance, such as tightly coupled systems, error as a measure of precision becomes helpful to ensure the smooth functioning of hardware and white noise operations.

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Error as the distance from the expected outcome is *one* type of error. Increasing precision to adjust our tools or performance in real-time is not practical. Identification of this type of error allows corrections in training, performance, and production processes *before* use in operations.

#### *White Noise Decision making*

A convergent, deductive, analytic approach makes sense in white-noise environments. We search for facts and information because they guarantee our deductive hypothesis. The structures we create, and our actions reinforce acceptance of the normative frame and the security they offer.

This linearity and stability, however, impede generating the stochastic resonance that brings stability to dynamic environments (22). Rigid structure and linearity will narrow and increasingly constrain our responses.

Decision aids in a linear, deterministic environment can use protocols, algorithms, and decision trees. Algorithms decompose a more extensive problem into minor problems that can more easily be solved. We complete one action before moving on to the next.

Decision trees identify alternatives and guide decision-making when the necessary information is unavailable (23, 24). They were first introduced for capital investment and then later applied to healthcare.

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Classical logic is central to decision-making in the white noise environment. We stress two well-known laws of classical logic because they may improperly be applied to red or pink noise environments. Some logic can incorporate multiple values, allow contradiction, and include ‘indeterminate’ truth values.

- *The law of excluded middle*—every proposition is either true or false. There is no gradation.
- *The law of noncontradiction*—the same proposition cannot simultaneously be true and false.

#### *White Noise Problem Solving*

White noise environments, despite their stochastic characteristics, follow the Gaussian distribution. Therefore, the Gaussian distribution of white noise environments supports discrete concepts, hierarchical systems, and linear thinking independent of context or the environment. The observer’s frame of reference moves outside the flow of events and becomes fixed as Eulerian specificities (25).

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***“Classification and standardization can solve the problem of information correlation in a white-noise environment. Precision supports distinct classifications, while standardization gives meaning to precision. Precision is reliable in white noise systems as we see repeated or similar actions which produce predictable results. That reliance on precision, such as ICD-10 or DSM codes, leads to loss of information while classifying a situation.”***

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Classifications act as objects for cooperation and create boundary objects for communication across infrastructure during a disaster (26, 27). Classifications build from data are not a problem in the Gaussian white noise environment, where more data narrows the variance to form a norm.

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The white noise environment contains Herbert Simon’s well-structured problem that is amenable to the algorithm (28, 29), solved much like a puzzle with a set number of pieces fitting into a pattern (21). Abstractions and concepts provide the basis for understanding and prediction. With the Gaussian distribution, problems tend to be information-dependent, and error measures the distance from the model or concept. Classical logic and scientific reasoning are used (30).

The environmental stochastic variance that may occur in the white noise environment can appear daunting to the uninitiated. Engaging in these events draws upon the values of initiative-obedience and creativity-conformity. These are opposing sets of cultural values (31). Such situations can be daunting to the uninitiated, leading them to believe they have experienced a reddened environment. Rather than engaging in the situation, they may completely defer to an individual they perceive as having experience or authority.

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### **The Red Noise Environment:**

We easily envision an event as something that, once initiated, moves forward, unencumbered by its past. We see it somewhat like Isaac Newton's First Law of Motion, "Every body continues in its state of rest, or uniform motion in a straight line unless it is compelled to change that state by forces impressed upon it." The event continues until something acts upon it, a white noise event.

In an open system, the event acts on the environment just as the environment acts on the event. Autocorrelation develops when past events influence current ones, or a system interacts with others. Autocorrelated events are more susceptible to feedback loops, allowing even minor or mundane noise signals to achieve resonance. In this way, unnoticed occurrences become amplified and consequential.

Autocorrelation creates oscillations in the various frequencies producing varying periods. Oscillations between demands and capabilities create bivalence, even multi-valences. Autocorrelated segments create time series that can branch unexpectedly. Fluctuations and change create new premises and the consequent necessity to change or find new solutions. This is red noise.

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Red noise has zero mean, increasing variance, and is autocorrelated in time by feedback. Elements are *not* independent; relations between elements are mutual or reciprocal; and information and data *increase* variance—a power distribution forms rather than a Gaussian distribution. As power distributions, the non-Gaussian nature of red noise distributions impairs our ability to use classical logic, rigid models, and distinct concepts. More data clouds our conclusions.

Red noise's spectral density creates forcing functions that become ubiquitous, not entirely random except by timing. Forcing functions emerge from known processes within normal variation, differing only in time scale and magnitude.

Red noise events, or residuals, are autocorrelated, meaning there is an increased chance that the event can continue, producing above or below-average conditions that cause environmental disruption (33, 34). Red noise explains the lasting correlation of effects from a single event (12, 35).

The environmental pressure of noise in red environments favors the specialization of a population. *Ecological* change and responses occur within the lifetime of individuals (15). Unique environments

in healthcare, such as the ICU, Emergency Department, and operating theater, operate in a red noise spectrum environment.

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The development of autocorrelation, described above, converts white frequencies to red or pink noise—not as a transition but more like a phase change to new properties without a change in composition. We can identify this difference when more data, or collecting data over a more extended time series, do not produce an expected better norm or stochastic model.

Karl Weick (personal communication) described these environments as “a mix of white and red, and that red is the thing to be avoided. Pink is the compenetration of white and red, and the mess sensemaking tries to untangle.”

A special relationship occurs at the ‘flicker’ frequency, the  $1/f$  oscillation, where an increased power spectrum at low frequencies produces abrupt, rapid fluctuations and catastrophic failure. This is ‘pink noise.’ The long periods of red frequencies or the rare flicker events of the pink frequency ( $1/f$ ) can mislead us into believing we operate in a white noise environment.

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### *Types of Autocorrelation*

*Time.* In a time series, temporal autocorrelation occurs when a previous time interval influences a time interval.

*Environment.* Spatial autocorrelation describes the patchiness of people or things. That is, values at neighboring points can partly predict the value at any one locality. People and things are neither distributed uniformly nor randomly (36). They are near others for a reason, such as an environmental forcing function or an internal

social process. Spatial autocorrelation can be positive or negative, representing aggregations versus scarcity.

In epidemiology, spatial autocorrelation identifies disease clustering in a general or specific region. Spatial autocorrelation measures the degree of similarity between objects located near each other (37). *As a form of contextualization, spatial autocorrelation heavily influences stress, fear, and threat.*

Spatial autocorrelation can cause the appearance of a 'false' gradient. In a 'true' gradient, neighboring elements are not coordinated, the changes in value deriving from their coordinates. In a false gradient, the change in value across space is caused by autocorrelation from the values and influences of its neighbors. The change in value is not due to its location (36).

**Behavior.** People, as social and learning organisms, demonstrate behavioral autocorrelation. Autocorrelation within a group creates culture, and the individual acculturates to that group through autocorrelation. Mirror neurons (38, 39) support team formation through autocorrelation. Autocorrelation of human behavior gives the reddened noise that confounds our ability to predict how others will act.

The human mind auto-correlates to the environment, that is, responds to feedback from behaviors, and the environment adjusts performance and creates learning. This is the basis for allostatic growth—strength through change. This mental autocorrelation creates the red and pink noise inherent to human cognition and behaviors.

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#### ***Red Noise Instability, Pink Noise Abrupt Change***

The frequencies of long-period red noise have significant spectral density; hence they carry greater power. As the power wave arrives, environmental elements and populations respond. Frequencies with the power to force a system or population to respond to the environment are forcing functions.

Forcing functions act on various scales; some occupy our attention while other, low-frequency events, erupt into significant crises. Forcing functions introduce emergent new properties into the system.

In systems dominated by lower frequencies, that is, increased redness, ecological processes predominate. Red noise creates the dangerous gap that forms between theory and practice (40, 41), discrete concepts and continuous perceptions (42, 43), and the academician and operator (7, 13). In these situations, environmental and population variation maintains equilibrium (11).

When the variance continues increasing regardless of the length of the measured time series, the noise spectrum becomes pink, or

$1/f$ , noise. As mentioned above, a special relationship occurs at the 'flicker' frequency, the  $1/f$  oscillation, where an increased power spectrum at low frequencies produces abrupt, rapid fluctuations and catastrophic failure. Pink noise power decays as the inverse of frequency, causing common and rare environmental events to gain equivalent weight in a pink environment (12). Midway between white and red noise, environmental pressure from pink noise equally favors a balance of generalization and specialization (15).

#### ***Red Noise Thought***

Upon detecting an acute threat, the amygdala activates the sympathetic-adrenal-medullary (SAM) and hypothalamic-pituitary-adrenal (HPA) axes. The SAM axis initiates the adrenergic “fight-or-flight” response, while the HPA axis releases peripheral adrenal hormones, including cortisol (44). The brain, reacting from bottom-up reflexive and priming processes, prepares the body for survival in the forcing function or amidst abrupt change.

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The brain decreases the influence of executive functions while enhancing motor behaviors and cognition. The amygdala causes the periventricular nucleus of the hypothalamus to secrete corticotropin-releasing factor (CRF). CRF simultaneously stimulates two systems: 1) the HPA axis to inhibit abstract thinking and memory and 2) the locus coeruleus-norepinephrine (LC-NE) system for adaptive thinking and behaviors. The brain is shifting to the adaptive cognitive shift necessary for survival.

Unmodulated, the brain response distorts cognition (situational cognitive distortions) (45).

- Anger
- Frustration
- Avoidance
  - Complete or avoid tasks
  - Focus on inconsequential tasks
  - Addressing easily accomplished tasks first
- Distractive comments
  - Responding to distractions

- Freeze (“attentive freeze”)
- Actual cognitive or physical freezing
- Nausea and avoidance
  - Urge to urinate or defecate
- Confusion
- Mental freeze
  - Inability to solve simple problems
  - Failure to recall knowledge
  - Impaired working memory
- Choke (expectations being observed)
- Impaired memory recall/enhanced procedural memory
- Loss of abstract thought when the prefrontal cortex and executive functions are impaired
- Concrete thinking and reasoning due to loss of abstract abilities (amygdala impairs cortex)
- Rules are abstractions, therefore, difficult to recall and use.
- Failure of cognitive strategies: “Even quite mild acute uncontrollable stress can cause a rapid and dramatic loss of prefrontal cognitive abilities” (46).

#### *Red Noise Information*

Noise contains information. Using noise as information improves prediction, alters our view of the environment (7, 20, 47), and changes how we think and reason (8, 25, 48, 49). Increased predictability better focuses vigilance, reduces exposure to vulnerability, and mitigates some of the effects on the system that arise from threats (20, 50, 51).

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Our view moves beyond situations within a specific space and time increases the flow of information within the system (52), distinguishes the boundaries of our capabilities, makes early heralds of failure visible, and clarifies covert, compensated system failure (13). We generate and update information, make more effective inferences from imperfect information, and process the evolving consequences of simultaneous acting and *not* acting (53). We begin to think by acting (54-57). A collaborative approach then emerges as a robust flow of safety improvement information consisting of, among other things, information about errors and near misses.

#### *Red Noise Accuracy and Correction*

Accuracy is proximity to the desired value or state and will improve with feedback. Accuracy works well for moving targets as it is a process, especially true in reddened noise environments. Through reciprocal feedback, we achieve and maintain accuracy.

Structures exposed to entropic dissipating energy must remain within a specified range for continued operations. Fluctuations in response to forcing functions increase the variance of measurements, indicating changing circumstances, knowledge limits, and performance boundaries. Error, wrongly considered a failure signal (58), has value in the HRO. Though red and pink noise environments are *information insensitive*, they are not feedback insensitive. Engagement generates information through real-time feedback despite rapid changes in human performance or the environment.

#### *Red Noise Decision making*

We have no time to vet information or evaluate events in a dynamic situation. We rapidly observe feedback that is *directly associated with immediate action*. That is, we respond to the environment responding to us. Reciprocal decision-making describes how we act, observe the response to our action and how that response guides our next action. We learn what works through action. Decisions linked to action are probes to learn structure, redirect trajectory, create structure, and engage the threat. This is not simple feedback, a component of decision trees and algorithms (8).

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Short feedback loops are more specific to our action and more readily accepted, rightly or wrongly, as causative. To obtain short feedback loops, we must closely approach the environment, even entwining with the environment. Entering the situation shortens feedback loops to improve accuracy.

Long and indirect feedback is disastrous in forcing functions or abrupt change. The time compression inherent to the flux of rapid, dynamic events confounds the real-time use of prolonged or indirect feedback loops.

*Negative and positive feedback.* Feedback maintains homeostasis for stable operations within the environment, supports safety, and generates self-organization WHILE simultaneously bringing resolution to the event.

- Negative feedback corrects deviations from our desired state, ensuring safety. Negative feedback marks our boundaries for safe operations.
- Positive feedback builds structure and supports our strength and resilience.

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#### *Red Noise Problem Solving*

Loosely coupled, overlapping, and gapping concepts create a confusing environment where the problems are ill-defined (13). Herbert Simon (28) described how we naturally use heuristics to solve ill-structured problems. Heuristics can create biased thinking (59), which can be corrected through error identification (25, 28, 29, 58). Motor cognition (60) corrects errors by acting, making errors visible and correctable (32).

The red noise environment is ecological, therefore, contextual and pragmatic (13). These problems are information-independent. We cannot easily differentiate information from noise. We search instead for clues, as in a mystery, rather than pieces of the puzzle (21). We will be generating structure as we generate information. Red noise has a power-law distribution.

The pink noise environment is also ecological, but the problem is embedded into the environment, making these problems contextual and pragmatic (8). Problem-solving tends toward practical common sense, focusing on consequences and a broad knowledge base (49). Reciprocal feedback decision-making methods, such as Boyd’s OODA Loop, provide flexibility (8). Actions through motor cognition (60) generate information by converting uncertainty to certainty (61).

Before his landing on the Hudson River, Capt. Chesley “Sully” Sullenberger had several discussions with one of the authors (DvS) about High Reliability and error management. Sullenberger had learned a helpful approach to capture and manage real-time errors: consider error a ball rolling down a ramp. The ramp has speed bumps that will stop the ball.

Sullenberger continued, “Another part of the idea is that it often requires more than one-speed bump to trap the error finally. If it goes fast enough, the ball may miss some bumps or roll over them. (The taller the bump, the more likely it will trap the ball.) Many

speed bumps represent ‘defense in depth,’ a military concept we also discussed that day. A multilayered defense system is less likely to be penetrated than a single layer.”

This is like increasing capture frequencies as the error (the ball) increases its speed. The “error ball and ramp” model that Sullenberger describes is a dynamic organizational design to reduce system failure that also recognizes the operator’s real-time efforts to decrease the chance of failure.

#### **Emergence and Self-Organization:**

In an open system, nonlinear interactions will entrain local elements unexpectedly. Self-organization creates new structures as the order comes to chaos. During this dynamic, novel properties will emerge to influence the system. Our efforts to engage a self-organizing system will encounter these novel properties. Reliance on standard approaches and plans will misdirect the efforts of operators.

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#### *Emergence of Novel Properties*

Emergent properties occur from nonlinear interactions at the local level. Though scientific principles do not change, emergent properties are often novel and may not fit into conventional schemes of description or action. Causation can be nonlinear.

In the flux of events, environment elements interact with each other in nonlinear ways. Entropy drives these local interactions, which help dissipate the energy through self-organization. A hallmark of self-organization is the emergence of novel properties within the system. These are not new principles but rather unexpected and sometimes transient properties. These properties test the capabilities of individuals and the organization and will confound the best plans.

Emergent properties occur from nonlinear interactions at the local level. Though scientific principles do not change, emergent properties are often novel and may not fit into conventional schemes of description or action. Causation can be nonlinear.

Forcing functions experienced by the individual illuminate the stress response functions and reveal weaknesses in leadership and the social fabric of the organization or culture. Novelty, uncertainty, and uncontrollability cause stress (41, 42), elements that are inherent to red noise.

- *“Novelty”* comes from the emergence of new properties during the nonlinear interactions of self-organization.

- *Uncertainty* is an inherent principle of linear, time-variant systems, a product of the stochastic frequencies in red noise. (Heisenberg's Uncertainty Principle is an example from quantum mechanics.)
- *Unpredictability* develops from stochastic frequencies and the rate of change in the logistic equation that can develop into deterministic chaos (43).

Reddened or pink-noise environments are information insensitive. More information (or data) makes the data messier or reveals covert, unexpected influences. With events in flux, current information quickly becomes antecedent information, entrained energy changes circumstances, and what was relevant becomes irrelevant.

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We generate information through our actions. There is no wrong action, as every action creates a response, and every response changes an element from uncertain to certain. This uncovering of information and the generation of information is Shannon Information (44). Claude Shannon laid the groundwork for the digital revolution by describing signals as having one of two values—“certain” OR “uncertain.” Information is the conversion of uncertainty to certainty. Certain carries no information, but changing from uncertain to certain creates information.

#### *Directed Self Organization*

Order comes out of chaos through self-organization (45). These systems stabilize and develop order by self-organizing through local, nonlinear feedback. Positive feedback contributes to growth and structure, while negative feedback restricts growth. These oscillatory, self-organizing processes bring stability and order to the environment, but the nonlinear interactions degrade any ability for predictions. Environmental self-organizing processes create stochastic noise that can increase to a level that forces a system or population to respond. The system or population responses to these forcing functions are also self-organizing oscillatory processes with poor predictability of outcomes.

For organizations, personnel and executives will become alert to subtle and nuanced disruptions, early heralds of failure, and covert, compensated states to engage early and more effectively.

Improvisation and learning by doing, components of Pragmatic HRO, generate solutions and reduce damage in unforeseen ways. HRO values and attitudes support personnel in their natural drive to find what works to help people who cannot help themselves. HRO, as the verb form, describes a scale-free network approach that overlays organizations and systems to increase sensitivity to early heralds of failure and increase interventions' effectiveness. While HRO methods move the organization toward a more

desirable end-state, it does not increase resources except mental performance.

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A practical domain of engagement recognizes the overlapping and loose coupling of concepts necessary to complete a task, also the pragmatic stance, and illuminates the study of the problems of transferring academic work to organizational practice. Engagement is the act of learning by doing in context, not an outcome of rational deliberation, and cannot be objectified for theory-making (41). Engaged action comes from insight and immediate feedback, with negative feedback marking the safe boundary of performance and positive feedback generating growth. All feedback generates information. “Mistakes” indicate a change in circumstances (62) or interference from the environment (63). However, mistakes are observable and, therefore, correctable (32). Effective responsiveness brings strength through change and allostasis.

The noise process is independent of timescale or magnitude; we need not characterize normal environmental variation differently from catastrophes (2). A disaster is an open system where energy and entropy freely flow.

When a NICU experiences a disaster, the external environment enters the NICU (46), and the isolated system, which constrains the flow of energy and entropy, becomes an open system. Energy and entropy freely flow in or out. Entropic energy, not available for practical work, changes order within the NICU system to disorder. Entropy is not a measure of disorder in the moment, such as scattered, randomized elements. Instead, entropy is a disorder with poor predictability because of an increasing number of possible permutations or futures. The more random the system becomes, the greater the number of possibilities that develop and the more significant the increase in entropy. The forcing function of stochastic environmental energy drives the disaster into the NICU, forcing the NICU to become an open system and increasing the possible permutations the Neonatologist must negotiate.

Self-organizing systems are dynamic, requiring continual interactions. The disaster environment is an open system with a

continual flux of energy and matter. Reactions, therefore, can occur away from their equilibrium state. Structures—termed dissipative structures—emerge through nonlinear kinetics. Patterns then arise from energy dissipation into the environment (47).

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Self-organization creates the oscillations and waveforms that disrupt the environment, forcing responses from populations. Self-organization is also the response of populations to reduce the effect of environmental oscillations. The flow of energy and entropy alter the self-organization of these oscillations. Stochastic environments become stable from the oscillations of self-organization; populations maintain stability through the oscillations of self-organization.

Self-organization can develop through behaviors due to decisions like a termite mound where termites deposit material from local physical cues. “Individual organisms may use simple behavioral rules to generate structures and patterns at the collective level that are relatively more complex than the components and processes from which they emerge” (47). This is from nonlinear amplification and cooperativity, making the results sensitive to the initial state.

#### **Protection from Red and Pink Noise:**

The threat of a forcing function or abrupt change can create an ecology of fear (4, 64). That is, the threat causes more harm by its absence than its presence. Individuals can manipulate the ecology of fear for individuals to self-police their behaviors and actions. We see this with liability fears, medical error, and patient harm or safety.

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The ecology of fear can bring in fears with a solid affective component, but they are less likely to occur. A disliked situation can be framed as a shared threat, even if it is not. Repeating descriptions of the harm it may cause soon engenders fear of something or someone we routinely encounter. The majority will voluntarily, if not spontaneously, find the cause and ‘fix it.’ That is,

the majority now assigns the blame (65).

Vigilance in the absence of the predator, a defense cost, sustains the stress response with chronically elevated glucocorticoid levels and reduced reproduction (66, 67). This is the consequence of accepting the ecology of fear in an organization.

#### **Defenses**

Defensive measures protect the organization from damage due to direct attacks and also protect routine operations from distractions. Karl Weick (personal communication) once described how his motivation for “sensitivity to operations” came from studies that demonstrated failure when a disruption had distracted the organization from its routine operations. Defensive measures must not detract from operations.

Patterns of defense differ if the risk is unpredictable, uncontrollable, variable, and the costs of defense are high (68).

- Proactive defenses have the most significant effectiveness when risks are predictable and controllable.
- Reactive defenses are more effective and reliable with increasingly unpredictable or uncontrollable risks.

Fixed constitutive defenses, such as spines, become effective when risks are consistently high or defensive costs are low. Risks often vary by location or over time, and defenses carry costs. Inducible antipredator responses allow the selection of antipredator behaviors with variable expression, increased behaviors for elevated risks, and decreased expression as the risk abates (68).

The mistranslation of HRO often supports standardization, central authority, and decision migration through rigid protocols. This approach is vital for a high-turnover workforce.

While reliable for white noise environments, it will mislead staff when novel properties emerge from forcing functions or during abrupt change.

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Inducible antipredator responses allow the selection of antipredator behaviors with variable expression, increased behaviors for elevated risks, and decreased expression as the risk abates [5]. We have an inducible antipredator response—terminate ongoing behaviors (the stress HPA axis) while initiating attention-arousal behaviors (the LC-NE system), which utilizes broad attention networks to sustain practical cognition under stress. This correlates well with Niko Tinbergen’s thesis that behavior is the more adaptive approach for animals in adverse or hostile environments.

## The Limitations of Design:

Administrators create emergency plans at “the corner of 70<sup>th</sup> and Fluorescent,” a fire department term describing office work where the room temperature is 70° Fahrenheit with fluorescent lighting. However, operations occur in the heat or cold, in the dark, possibly wet, with the dictum, “If you don’t have, it doesn’t exist.” HRO bridges this gap between planning and operations through improvisation.

Nevertheless, it is not that simple. However, the drive for security from structure too readily leads to people creating or conjuring structures through technical designs such as hierarchy and rules. These technological systems “become organized by commands from the outside, as when human intentions lead to the building of structures or machines”—Eugene F. Yates (69). Executives, administrators, leaders, and planners work “from the outside” as technical designers but act as spectators.

Their knowledge develops from descriptions rather than gaining knowledge through acquaintance and experience (70). Information paradoxically becomes more confident with distance (71). This is particularly true for those with limited and underfed experience before advancing to their position or relying heavily on business management or organizational science.

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George Orwell (72), as a local British government official in Burma, describes the effects distance and proximity have on information and the degree of the threat. An elephant was ravaging a village’s bazaar. Locals asked him to “please come and do something about it.” As he traveled to the village, he found the “story always sounds clear enough at a distance, but the nearer you get to the scene of events, the vaguer it becomes.”

Spectating leaders and administrators unable to engage the gap may fear that operator improvisation is a weakness within the system and a point of vulnerability in operations (3). Engagement,

the “engine” of HRO, can appear to be unconstrained freelance behavior within the healthcare culture. Physicians and surgeons may deride someone who quickly engages through improvisation as a “freelancer” or a “loose cannon.” These are people alleged to lack the control necessary to join with others and conform to medical practice or follow medical direction. What is missed is the importance of immediate engagement with uncertainty and threat. Spectators wittingly or unwittingly disregard local forcing functions of the red noise environment (4).

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Before events of a forcing function become visible, local nonlinear interactions and self-organizing have occurred. “Natural systems become structured by their own internal processes: these are self-organizing systems, and the emergence of order within them is a complex phenomenon”—Eugene F. Yates (69). Improvisation is self-organizing with human intention but from *within* the flow of events (73, 74).

### Transition to Red Noise:

The stability and predictability of a white noise environment have great utility for science. Researchers can isolate time segments and control entropy. Elements are generally independent and random. Researchers can change a single variable in this everyday environment of near isolation, and things still work.

We can describe the elements of the white noise environment through statistical analysis. We do not need to be there. Reliable predictions follow probability distributions. We have reliable plans. When in doubt, we increase our certainty by collecting more information and reducing data variance. Administrators become “data-driven.”

Plans then have the beauty of an architect’s precise drawing. The

ability to achieve precision makes the tight coupling of elements work well. Evidence-based medicine informs and refines protocols for safe and effective healthcare delivery. Error measurement becomes an efficient monitor for the early identification of unsafe deviations.

Do things right, and no one gets hurt. That is the security of the white noise environment. Because the white noise environment can be mastered, experts have allowed it to develop concepts, categories, standards, norms, and what we teach. Reasonable rules and effective protocols, well-worked standards and practices, are all smooth and clean—attractive to the administrator, regulator, and spectator while being easy for a high turnover workforce.

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In the 1990s, the California State EMS Authority created a committee of physicians to develop Uniform Treatment Protocols for paramedics. Membership was chiefly comprised of experienced Emergency Physicians with operational military and firefighting experience. EMS physicians had limited paramedics to strict protocols such that all unresponsive patients received a bolus of dextrose and naloxone in a specific order.

One of the authors (DvS), a committee member, had advocated listing up to five treatments BUT without a numeric or alphabetical notation that suggested a proper order. The basis of his argument was using nalorphine for field treatment of opiate overdose. The respiratory depressant effect of nalorphine would amplify the respiratory depressant of barbiturates in an overdose. Physical exam for pinpoint pupils was mandatory.

The introduction of naloxone, which does not have respiratory depressant effects, made the exam less significant. Paramedics at the time did not stop examining eyes because pupil response could reveal other problems. The author learned through observation and discussion that, by the 1990s, many paramedics and Emergency Physicians routinely gave dextrose and naloxone with less emphasis on physical exams. Committee members recognized the prevalence of this problem. The solution was to list actions for the paramedic to choose the order based on history and physical examination.

The committee continued its business, moving through various physiological systems, diseases, and treatments until the committee reached the cardiac system, when a discussion was developed on whether to develop protocols for California paramedics or follow the Heart Association protocols. After a bit, the author asked committee members, “Have any of you

used one Heart Association protocol one time?” After a pause, the physicians gave a unanimous answer—“No.” The protocols developed followed a more fundamental approach.

The physicians on the committee came from red noise environments in life, prior careers, and where they practiced Emergency Medicine. They filled in their gaps in knowledge or the gaps between rules by improvisation.

#### **Improvisation Engages Red Noise:**

Forcing functions and abrupt change challenge an organization’s hierarchy and plans. Organizations operate with tightly coupled systems. The map of the systems then becomes the territory of its operations, constraining and reshaping that territory. If relations among labels on the maps are treated as expectations, the tighter the coupling, the higher the probability of surprise in a crisis.

In a loosely coupled system, maps can be separated from coordinated action more readily. As a result, improvisation, workarounds, and experiments are more common. This description suggests a parallel between intuition and the activity of improvisation. Improvisation also tends to be rapid, non-conscious, and non-sequential. We sense through feedback, and feedback is the start of improvisation. There can be no rules because of the vagueness.

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***“Forcing functions and abrupt change challenge an organization’s hierarchy and plans.”***

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Acceptance is critical for engagement and improvisation. Acceptance is the absence of judgment. Acceptance is also a critical element of comedy improvisation and is the gate for HRO improvisation. When we self-organize under intention, we are improvising. Otherwise, our responses are random at worse and trial-and-error at best, and neither lead to learning. Also, in Dewey’s pragmatism, acceptance intercedes between causation and action. Acceptance is *why* you do not need causation.

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***“Acceptance is critical for engagement and improvisation. Acceptance is the absence of judgment. Acceptance is also a critical element of comedy improvisation and is the gate for HRO improvisation.”***

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Passage through the liminal space is active rather than passive. From the “concept stance,” one would expect planning to prepare a person and plans to guide actions. Sean McKay (75) answered the criticism of improvised plans regarding the fire department response to a terrorist shooting. The department moved 14 patients from the triage site in 18 minutes with no deaths. “They didn’t improvise a plan. Their plan was improvisation.”

In 2017, Karl Weick and one of the authors had a series of emails regarding improvisation.

“Gilbert Ryle (1979) discussed improvisation as one means to convert knowledge and doubt into adaptive action. He

argued that virtually all behavior has an ad hoc adroitness akin to improvisation because it mixes a partly fresh contingency with previously learned general lessons. Ryle describes this mixture as paying heed. Improvisation enters in the following way. '(T)o be thinking what he is here and now up against, he must both be trying to adjust himself to just this present once-only situation and, in doing this, be applying lessons already learned. There must be in his response a union of some Ad Hockery with some know-how. If he is not improvising and improvising warily at once, he is not engaging his somewhat trained wits in a partly fresh situation. It is pitting an acquired competence or skill against an unprogrammed opportunity, obstacle, or hazard. It is a bit like putting some new wine into old bottles' (1979, p. 129)."

Engaging is improvising without knowing what will work or what direction is possible.

### Conclusion:

"When faced with a void, move forward," Jim Denney, Capt., LAFD, a veteran of two Vietnam combat tours, would tell his crew. An LAFD firefighter, approaching a volatile incident to assist one of the authors (DvS), uttered a powerful version of a pragmatic stance: "I may not know what's happening, but I know what to do."

Engagement describes the above approaches. Engagement is experiencing a situation when the operator does not know what will work. "HRO uniquely shapes the engagement that moves through and out of a liminal period"—Karl Weick (personal communication).

Engagement is the initiation. Denney and the firefighter are creating something from what is immediately around them. This is improvisation. They start *without a plan*.

The best-laid plans of administrators and spectators often go awry. *Go without a plan*. One of the authors (DvS) visited the compound of a Special Group of Special Operations Forces. Talking to a senior noncommissioned officer, the author mentioned the reality of emergency responses—failure is an option. The officer considered commissioning shirts for the unit with that phrase. They discussed mission planning on short notice. Sometimes they develop a plan before leaving, sometimes on the way, and often have no plan. On deeper reflection, they realized that "without a plan" had more power. "When you pay attention to the plan, you are ignoring information and become frustrated when the plan does not work"—Chris Flowers, San Bernardino (CA) Police Department, one of the first officers on the scene at a terrorist shooting and a school shooting.

These are not rare occurrences. Human behavior develops from experiences, perceptions, and affective interpretations of any situation. Human behavior is red noise. The presence of a human changes a white noise environment to one of red noise. Despite this, people continue to engineer strategies, plans, protocols, and rules for a white-noise environment.

Encountering reddened noise, people seek information. An LAFD Battalion Chief described the information as a 'hot potato'—"you don't want to hold on to it, so you quickly throw it to someone else." In healthcare, however, the value of information keeps it from being shared. People enter healthcare because a medical condition creates a red noise environment. Their response is the same for anyone encountering red noise. The difference is that the patient and family must enter the healthcare environment—a liminal zone. Queries are often met with "A little *knowledge* is a dangerous thing."

Alexander Pope, in "An Essay on Criticism" (1711), wrote, "A little learning is a dangerous thing." However, Pope wrote with a different purpose than restricting learning. His following lines are:

Drink deep, or taste not the Pierian spring:  
There shallow draughts intoxicate the brain,  
And drinking largely sobers us again.

Safety comes not from learning 'dangerous' information but from learning, experience, and engagement. Engagement becomes improvisation when the operator has information, knowledge, and support. Repeating tropes about the danger of knowledge and restricting the curious mind created not only the ecology of fear but people who will police themselves, relinquishing their values of initiative and creativity.

Pope's poem continues:

"In fearless youth, we tempt the heights of Arts,  
While from the bounded level of our mind  
Short views we take, nor see the lengths behind;  
But more advanced, behold with strange surprise  
New distant scenes of endless science rise!"

Pope urges us to climb higher for grander views, extending ourselves into new environments. In this article, we have presented improvisation for operations in the red noise environment. That is like saying improvisation is a tool that could readily be relegated to a toolbox. This metaphor of tools and toolboxes seems favored by those who have never carried one around or worked under a car. We never hear about the function of a tool. Improvisation has a place in red noise environments. Does it have a function?

That is the subject of the next article in the Improvisation Series.

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*Sean McKay  
Executive Partner / Director, Disruptive Rescue & Austere  
Medicine  
Element Rescue - Response Solutions within Nonlinear Complex  
Environments  
Greenville, South Carolina, United States*



*Thomas A. Mercer  
Rear Admiral  
United States Navy (Retired)*

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**NT**

**Corresponding Author**



*Daved van Stralen, MD, FAAP  
Associate Professor, Pediatrics  
Department of Pediatrics  
Loma Linda University School of Medicine  
11175 Campus Street  
CP-A1121  
Loma Linda, CA 92350  
Email: [DVanStra@llu.edu](mailto:DVanStra@llu.edu)*

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Karl Weick, Rensis Likert Distinguished University Professor of Organizational Behavior and Psychology, Emeritus, University of Michigan

William J. Corr, Captain II, Los Angeles City Fire Department (retired)

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Errol van Stralen, Ancora Education